A SEARCH FOR ANALOG PROCESSES IN ORIENTING TO SOUNDS FROM DIFFERENT LOCATIONS

A Thesis submitted in partial fulfilment of the requirements for the degree of Master of Arts in Psychology at the University of Canterbury.

by

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1986

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ACKNOWLEDGEMENTS

I would like to acknowledge the work of Ian Douthwaite and Colin Burnett in preparing the computer program which ran the experiments reported, Stuart McKenzie for preparing the program used in the statistical analysis of the data, and Glenn Lewis for building the sound amplification equipment.

My thanks go to my Supervisor, Paul Russell for friendly, enthusiastic help and guidance, and to all those who kindly volunteered their time as subjects for the experiments.

ABSTRACT

Eight experiments are reported in which subjects were encouraged to direct their attention to auditory imperative stimuli. Task requirements ranged from simple detection to tone matching. Results are interpretated as supporting the assertion by Russell (1985), that subjects can successfully orient their attention to auditory stimuli. When the stimuli are spatially separated in tone matching tasks, reaction times are progressively slowed with increasing separation. Two explanations for this phenomena; based either on phenomena association with the matching task, or the orienting of attention, are proposed. An attempt to decide between these explanations was inconclusive.

Positioning all the potential stimulus locations in the same hemifield did not result in any lessening of the effect (on RT) for spatial separation. This result, which is in disagreement to conclusions drawn by Hughes and Zimba (1985), for visual stimuli, is interpreted on support for Eriksen and Yei-yu-heh's (1986) Zoom lens model of attentional allocation, proposing a variable spatial extent for the receptive field of attention. The amount of discrimination required by a task appears to be an important feature in determining the size of the spatial extent of attention.

INTRODUCTION

The question of how one prepares to select certain kinds of information over others is of considerable interest in psychology. The term orienting is used to describe these preparatory processes (Posner, 1978.) Acknowledgement of the role of attention in preparatory processes dates back to Helmholtz (1850) and William James (1890). Enhanced processing of stimuli to which one has oriented can be shown to apply when selective preparations are made to stimuli which differ on the dimensions of location, modality or semantic class (Neely, 1977; Posner, 1978, 1980). Orienting to location is of particular interest because of its ability to illuminate the roles of sensory and attentional factors in controlling our awareness of the environment.

The most successful, least open to dispute demonstrations of orienting have used model tasks (Posner, 1978; Posner, Snyder and Davidson, 1980), in which the input is as simple as possible so that little, if any, semantic associations can take place. Simple luminance detection is a popular task with performance measured by reduction time (RT). In such experiments trials typically proceed as follows: First a warning signal (WS) is presented in an attempt to control levels of alertness (Posner and Boies, 1971; Webb and Obrist, 1970). This is followed by a cue (usually a visual arrow,) which informs the subject of the probable location, on a computer screen, of the impending imperative stimulus and encourages subjects to shift their attention to that location. Cues vary in validity with a high proportion, usually 70-80%, correctly predicting the location of the imperative stimulus (valid cues) and the remainder being either neutral (uninformative) or invalid (the stimulus occurs in a different position to that indicated by the cue.) The cue is followed by the imperative stimulus and feedback concerning the speed of the response. Subjects' reaction times typically show benefits in terms of greater speed when given a valid cue, and cost when they receive an invalid cue. This cost-benefit analysis (Posner and Snyder, 1975) is a powerful tool for distinguishing whether the facilitation derived from cueing is due to automatic pathway activation, which has no inhibitory consequences, or the commitment of a cultural processor, involving widespread inhibition to other pathways. A pattern of RTs showing costs and benefits dependent on cue validity is regarded as a clear demonstration of attentional orienting and is termed an orienting effect or simply, orienting.

Posner, Nissen and Ogden (1978) used the term 'set' (after Gibson, 1941) to refer to this alignment of attention with input pathways and demonstrated experimentally that one can orient to locations in visual space independently of overt sensory adjustments. The presence of a limited capacity mechanism, revealed by costs and benefits in RT dependent on cue validity, combined with an elimination of overt sensory adjustments through the monitoring of eye movements by electro-oculogram, argue persuasively that subjects can covertly direct their attention towards positions in visual space.

Arguments that this pattern of results may merely reflect differential criterion setting by subjects are rejected by a number of features observed in the orienting situation. Analysis of subject errors when the task involves discrimination show, contrary to predictions from signal detection theory, that errors are lowest at the cued or expected position. Also one typically fails to obtain an orienting effect unless subjects are cued on every trial indicating that the expectancy must be actively maintained. Posner et al (1980) concluded that these features argue that central control actively modifies the stimulus evidence rather than merely providing a criterion for choices among fixed states of evidence.

While Posner (1978) speaks of both sensory and conceptual orienting as the process of aligning central attention with a particular pathway, be it physical location, sensory channel or semantic class, as a general characteristic of human information processing, he failed to replicate the visual results for auditory or tactile stimuli. Subjects showed no evidence for the commitment of a central processor to the cued locations when the stimuli were presented to these modalities. In the light of the proposed central nature of the orienting process these results are unexpected. Posner explained them as being due to differences in the spatial layouts of the auditory and visual cortex and to fundamental differences in the ability of stimuli from different sensory modalities to activate alerting mechanisms (Posner, Nissen and Klein, 1976). Auditory and tactile stimuli, it was proposed, unlike visual stimuli, are automatically alerting. Because of this, orienting appears to be a necessary pre-condition for subjects to detect a visual stimuli. An informative fore-cue therefore, is of more use to subjects when they receive visual imperative stimuli than for imperatives from other modalities.

Recent work at the University of Canterbury however, obviates the need for these (post hoc) explanations. Covert orienting to auditory imperative stimuli has been demonstrated based on fore-cues informing subjects as to the location (Russell, 1985) or pitch (Dunford, 1984) of the imperative.

Russell and Dunford derived their success by requiring subjects to make a discrimination between the locations or pitches of the sound sources - a discrimination based on the cued dimension of the imperative. To achieve this they included trials in which a sound from one of the locations or pitches was not to be responded to. This procedure presumably forces subjects to pay attention to the cue and imperative and therefore overcomes the tendency of subjects to rely on the automatically alerting nature of the imperatives to perform the task.

These experiments present a persuasive argument, in line with Posner's general principles concerning the central nature of orienting, to the effect that attention can be aligned with input pathways regardless of sensory modality.

A distinction has been made between voluntary and automatic control over this alignment of attention. Jonides (1981) proposed that central and peripheral cues elicit orienting from these two different loci of control respectively. Jonides demonstrated that subjects in orienting tasks with peripheral cues were less affected by the extra capacity demands of a dual task and showed more resistance to suppression and less sensitivity to changes in expectancy than subjects who were given central cues. He concluded that the two types of cue seemed to mediate shifts of attention in qualitatively different ways. These can be related to the distinctions between exogenous and endogenous control proposed by Posner (1978) and automatic and controlled processing; (Shiffrin and Schneider, 1977).

The consequences for information processing of attending to a position in space have been well documented. More recently it has also been shown, for visual stimuli, that attention moves to these positions in an analog manner. Rather than making a discrete jump, attention traverses a set of intermediate points when moving from one position to another. Shulman, Remington and McLenn (1979) encouraged subjects to move attention to a location some eighteen degrees from fixation through the use of centrally presented arrow cues. The results showed typical costs and benefits in reaction time dependent on the validity of the cue in a similar manner to Posner et al (1978). The experiments of Shulman et al however, also had infrequently probed positions mid-way between the fixation point and the position of the cued imperative stimulus. By varying the stimulus onset asynchrony (SOA), the period of time between the onset of the cue and the onset of the imperative, Shulman et al were able to show that this intermediate point received facilitation relative to the far expected location at intermediate SOAs, particularly at 150 and 200 milliseconds. No such facilitation was found for the intermediate point for trials when an invalid cue was presented. It was proposed that this relative facilitation reflected the presence of attention of the intermediate location as it made its traverse from fixation to the expected position of the imperative. Attention, it seemed to Shulman et al, moved like a spotlight through the visual field illuminating intermediate points during its traverse.

This idea has gained further support from Tsal (1983) who presented imperative stimuli at locations corresponding to 4, 8 or 12 degrees left or right of fixation. Peripheral cues were used to attract attention and the imperative stimuli were one of two visual letters which had to be identified. Tsal found that the SOA at which identification latencies reached their asymptotic minimum increased in a linear fashion with the distance of the stimulus away from fixation. It was argued that this value of asymptotic SOA served as a measure of the time it took for attention to move from fixation to a given location, and concluded that attention moved in an analog fashion at a constant speed across the visual field. Tsal calculated the velocity of this movement to be approximately one degree per eight milliseconds.

The 'spot-light' metaphor of a spatially restricted beam of attention has been questioned in a recent paper by Hughes and Zimba (1985). Hughes and Zimba found that the costs and benefits which develop as a result of expectancy-manipulated attentional shifts, do apply (for visual stimuli) when all the potential imperative locations are in the same hemi-field. Only when the expected and unexpected locations are on opposite sides of the vertical meridian does one see the development of the typical pattern of costs and benefits.

The slower RTs to stimuli occurring at unexpected locations have been attributed to the time course of post-imperative attentional movements (Posner, 1980). Hughes and Zimba's proposal; that attention is not a spatially restricted phenomenon appears incompatible with this explanation. It is also, clearly incompatible with Shulman et al (1979) and Tsal (1983) both of whom have produced results which appear to demonstrate the presence of a spatially restricted, mobile beam of attention.

There may in fact be no conflict between the results of Hughes and Zimba and Tsal (1983), Shulman et al (1979) and Posner's extensive work (Posner, 1978; Posner et al, 1980). Recent studies by La Berge (1983) and Eriksen and Yei-yu-yeh (1986) provide evidence that, for vision at least, the receptive field of attention varies in size depending on upon the degree of resolution or detail required by the task. Thus one would expect the receptive field of attention to be large if the task requires detection of clearly supra-threshold stimuli in a dark environment, as was the case with the Hughes and Zimba experiments. The presence of a cluttered visual field or requirement to perform some other form of discrimination would be likely to induce a small focus of attention.

The hypothesis that the size of the attentional spotlight is variable depending on the degree of resolution required also explains the discrepancy between Posner's (1978) failure to find evidence for auditory locational orienting, and the results of Russell (1985) and Dunford (1984). It may plausibly be argued that the requirement to distinguish imperative tones from extraneous sounds produced the orienting effect because it induced subjects to narrow the extent of their attentional focus. Posner's experiments were conducted in a quiet room, where the receptive field of attention, by this explanation, would be large and diffuse.

A number of experiments and pilot studies are reported. The initial aim was to devise an experiment based on Shulman et al, which was capable of demonstrating that the focus of auditory attention, like its visual counterpart, traversed a path from a "fixation" location across intermediate positions to a cued location. Such a demonstration would lend further support to the claim that mechanisms of locational orienting are not, as Posner (1978) proposed, modality specific.

EXPERIMENT 1

The successful application of the procedure of Shulman et al to an auditory situation requires, as a pre-requisite, a task which provides a robust and substantial detection latency difference between tones occurring at expected (validly-cued) and unexpected (invalidly cued) locations, a means of ensuring that the spotlight of attention is resident at a central 'fixation' point prior to the onset of the cue, and which allows for fine control of cue-imperative intervals.

Russell (1985) and Dunford (1984) report that a necessary pre-condition for sensory orienting is the presence of stimuli similar to the imperative stimuli, to which no overt response is required. Merely replacing usual cues with the spoken cues "left" and "right", has been shown sufficient to produce auditory locational orienting (Russell, 1985). In the present experiment these extraneous sounds came in the form of an aural warning that a trial was about to commence, and aural feedback regarding the speed and appropriateness of the response. It was hypothesised that these sounds, which were presented from a centrally located speaker, would achieve the central focusing of attention prior to cue onset, and result in an orienting effect. These messages were chosen in preference to aural cues because of the difficulty in controlling SOAs inherent with spoken cues. Like Shulman et al, left and right pointing arrow cues were used. The experiment was thus identical to the auditory orienting experiments of Posner et al (1978) except that the visual warning signals and feedback were replaced by aural ones, and no neutral cue condition was included.

The present experiment did not manipulate SOAs, nor probe intermediate positions between the centre and peripheral target locations. The aim was simply to evaluate a procedure which might ultimately be used to do so.

Method

Subjects:

The subjects were nine unpaid volunteers from first year Psychology courses at the University of Canterbury. They were aged between 18 and 22 years.

Apparatus

The experiment was controlled by an Apple II+ computer. The white on black arrow cues, which cast horizontal and vertical visual angles of 22 and 14 minutes of arc were generated using the computers high resolution graphics facility and were displayed on a Kaga KS 14p monitor situated 1.9 m directly in front of the seated subject. Aural messages were produced using a Votrax model 100 Type 'n Talk voice syntehsiser and emitted from a 100 x 60 mm elliptical speaker mounted in a 180 x 125 x 75 mm box, located just above the monitor. The imperative stimuli were square wave tones produced by an assembly language routine which toggled the computer annunciators to produce the 220 hz tone. Wave form and frequency was checked by osciloscope and a Trio DF-760 frequency counter. The annunciator outputs from the computer games paddle connector, were amplified by National semi conductor LM 383 amplifiers and emitted from two 110 mm diameter speakers each mounted in a 200 x 180 x 90 mm box suspended from the ceiling at subject head-height and placed 1.86 m to the left and right of, and colinear with, the computer screen. The speakers were approximately 44° to the right and left of the subject. Tones were of loudness 51 dBA measured at subject head location using a Dawe Type 1400E sound level meter. Subjects reported detecting a tone by depressing a morse key with the index finger of their preferred hand. The experiment was conducted in a quiet room illuminated solely by fluorescent tubes.

Stimulus durations and inter stimulus and inter trial intervals were produced and RTs measured by the computer to within millisecond accuracy employing assembly language software timing routines (Price, 1974). Timers were synchronised to screen displays following procedures presented by Cavanagh and Anstis (1980).

Procedure

Each trial began with an auditory warning signal 'ready', spoken from the voice synthesiser. This was followed, approximately one second later, by the appearance of the left or right pointing arrow cue in the centre of the screen. These cues remained in view for a randomly determined interval of between 400 and 600 milliseconds. On other thru catch trials the offset of the cue was followed within about 50 ms, by the imperative tone which sounded until a response was made. Following the response, or a 1000 ms period for catch trials, the aural feedback was presented. An interval of 2000 ms was allowed for feedback, followed by a randomly determined inter-trial interval of between 500 and 3000 ms.

Two blocks of 106 trials were presented, the first of which was treated as practice. Within each block the location of 64 tones were validly cued and 16 were invalidly cued. Twenty - six catch trials were presented. In all three conditions the left and right locations were equally probable. A different, random ordering of conditions was used for each subject and each block.

Following the subject's response, or catch trial interval, subjects received feedback from the voice synthesiser. If a correct detection was made subjects received either their RT in milliseconds or the words 'Time exceeded' if their RT exceeded 1000 ms. The words 'Anticipation error' were presented if a response was made before the imperative tone was presented, 'No key press required' if subjects responded to a catch trial, and 'Catch trial' if a response to a catch trial was withheld.

It was summised that the variable cue-imperative interval, the presence of catch trials and the detection of anticipations would combine to prevent subjects from using cue-offset or elapsed time since cue-onset instead of the tone onset, as the basis for responding. The time exceeded message was intended to induce subjects to respond as quickly as possible.

Subjects were instructed to look straight ahead at the screen at all times, and to press the detection key as quickly as possible following the onset of the imperative tone. No head movements were observed. The need to minimise errors was stressed. Error data on the number of anticipations, responses to catch trials and overly slow responses were displayed on the screen following the practice block.

Prior to the practice block all subjects completed a preliminary auditory location test in which they indicated, with a left or a right key, whether the tone had sounded from the left or right speaker in a random sequence of tone locations. All subjects reached the criterion of 15 consecutively correct responses in the minumum of 15 trials.

This preliminary, and the two experimental blocks took about 35 minutes in total to complete.

Results and Discussion

There are a number of pre-conditions wich must be met in order to make meaningful interpretations of the RT data. The first of these is the elimination of overt head movements toward the likely location of the imperative in response to the cue. Such overt preparatory movement would make inferences about covert orienting of attention meaningless. Such preparatory head movements however, would also be substantial and obvious to an observer.

No such movements were observed.

The other pre-conditions to be met concern the error data. High rates of anticipatory responding or incorrect responses to catch trials imply that subjects may be responding to temporal information gleaned from cue presentation, rather than the onset of the imperative. In fact there were very few of either type of error. The probability of anticipation on any one trial, averaged over all subjects was only .009. The probability of a false alarm response being made on a catch trial was only .008. Trials on which anticipations were made were re-run.

In treating the results of this and all subsequent experiments all RTs less than 100 ms and greater than 1000 ms were rejected from further analysis. Such short or long RTs were thought to result from processes extraneous to the purpose of the experiment such as a late anticipation in the case of short RTs, or concentration lapses or insufficient pressure on the response key in the case of overly long responses. Only six RTs fell outside the cut off boundaries, a probability of occurrence on each trial of .008.

The median of RTs for each subject in each combination of cue condition and location was obtained. Group mean RTs as a function of cue validity are presented in Figure 1. The medians were subjected to a cue condition x location, within subjects ANOA using Lanes (1981) general analysis of

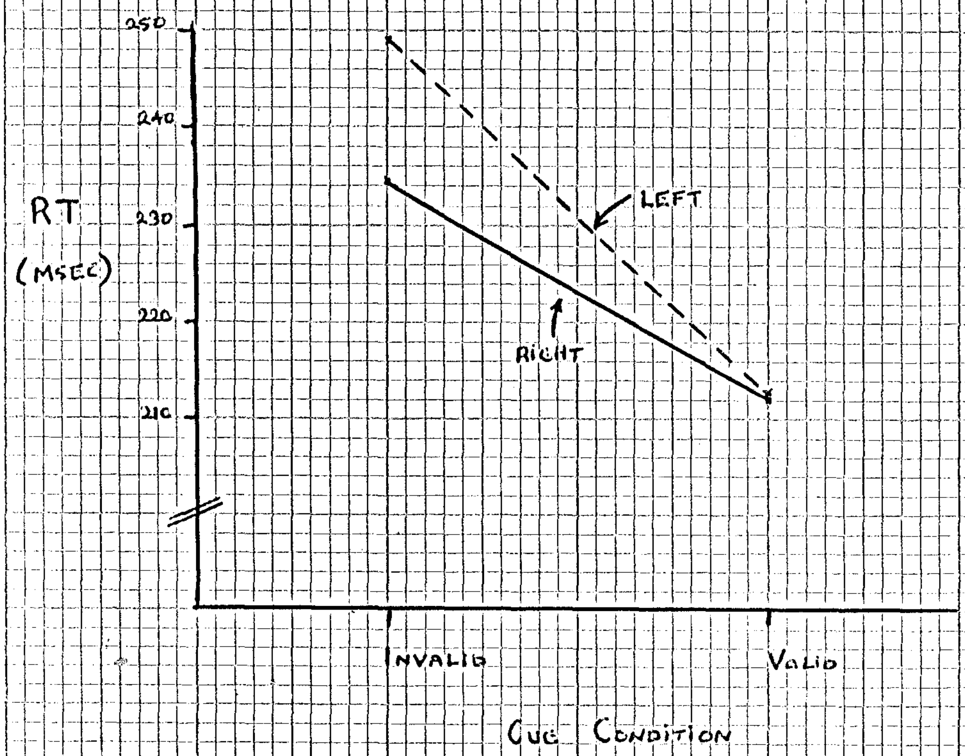

Figure 1. Experiment 1: Group mean RTs as a function of cue condition and location.

variance program, (which was also used on all subsequent analyses). This program enables within subject degrees of freedom to be adjusted in accord with the degree of conformity of the data to the assumption of equality of co-variance matrices. Adjusted degrees of freedom have been used in the assessment of significance levels. None of the measures, however, reached significance.

Like Posner's (1978) experiments with auditory stimuli the present task has failed to provide evidence for auditory locational orienting. It is, therefore, of no use in the present content. Russell (1985), however, demonstrated an orienting effect using a similar task. To achieve orienting in such experiments it is necessary for subjects to distinguish sounds for which it is appropriate to push the response key from those requiring no such response. Such discriminations may be based on qualitative differences between sounds (eg tones vs synthetic speech), their spatial positions, or their temporal positions in the sequence of a trial. It is proposed that the greater temporal separation of the warning and feedback from the imperative tone in the present experiment may underlie the difference between the present results and those of Russell. Subjects in the present experiment were able to use these temporal cues to distinguish sounds to which a response was required from the other sounds in the experiment, whereas Russell's experiment which used aural cues may have demanded a greater reliance on sound quality and source location, thereby resulting in a narrowing of the receptive field of attention.

EXPERIMENT 2

In response to the results of Experiment One, it was deemed necessary to revise a number of features of the experimental procedure. This experiment incorporates those revisions and was run in order to evaluate these new features.

The revisions included the introduction of pitch cues. These were included because they were auditory, and therefore more likely to sharpen the focus of the auditory attention, and because they would presumably locate auditory attention at the centre for the beginning of each trial. Pitch cues were chosen in preference to aural presentations of the words 'Left' and 'Right' because they allow for tight time control of SOAs which spoken cues do not. The mental effort required to derive the locational information from pitch cues was thought likely to more effectively force subjects' attention to the centre at the beginning of each trial.

Catch trials were replaced by tones presented from a central location to which no response was to be made. The expectation was, following Russell (1985), that this forced discrimination on the cued dimension would aid in the achievement of an orienting effect by sharpening the focus of attention, and by removing the possibility that subjects would rely on the automatically alerting nature of the stimuli and simply respond to any presentation of the tone regardless of location.

Aural warning and feedback were given, as in the previous experiment.

The other major aim of the experiment was to establish the time course of the development of orienting as a function of the cue imperative interval, in order to devise a suitable range of SOAs for use in later experiments.

Method

Subjects

One subject, the thesis supervisor was used. He was highly practiced at the task and had completed several blocks using the pitch cues prior to the experiment.

Apparatus

The apparatus was identical to that used for Experiment 1 except that a centrally located, ceiling mounted speaker was used to emit the tone cues and the to-be-ignored catch tones.

Procedure

As in Experiment 1, the subject was seated directly in front of a centre speaker and voice synthesiser speaker 1.9 m away, and instructed to look straight ahead at these speakers. The task was to respond by pushing the detection key as fast as possible upon hearing the imperative stimulus (a 220 hz tone at 51 dBA) when and only when the imperative tone came from either of the two outer speakers; located 1.86 m either side of the centre (44^{o} of angle to the left and right). No response was to be made to imperative tones from the centre speaker.

Each trial began with a warning signal; the word

'Ready' presented from the voice synthesiser. This was followed by the cue; either a 1300 hz or 5000 hz tone, with the low tone meaning the left and the high tone meaning the right speaker. The cues were delivered by the centre speaker and had a duration of 30 ms.

Following the onset of the cue there was a variable time interval (SOA) before the onset of the imperative stimulus. SOAs, which were presented in 106 trial blocks, were of either 1080, 580, 380, 180 or 80 ms duration and were presented in blocks in that order.

Aural feedback followed the subject's response and was identical to that given in Experiment 1. The words 'no key press required' were not presented when subjects made an inappropriate response to a stimulus tone from the centre speaker. Once again a randomly determined interval in the range of 500 to 3000 ms separated trials.

Of the 106 trials per block 64 were valid trials, 16 were invalid, and 26 presented the imperative tone from the to-be-ignored speaker. For trials on which a response was required, therefore, 80% of the cues were correct in their prediction of the location of the imperative. Stimuli were presented in random order within blocks, a different random order being used for each subject and each block.

Results and Discussion

Median RTs for each combination of cue validity x location x SOA were recorded. Figure 2 shows median RT to respond to the imperative as a function of SOA for each of the four conditions of cue validity and location.

Although both valid and invalid trials produced very similar RTs at an SOA of 80 ms, clear differences between valid and invalid trials are apparent by 180 ms. The orienting effect appears to reach an asymptote by 380 ms, after which there is little change in the speed of responding for valid trials. According to the rationale of Tsal (1983), this measure of asymptolic SOA indicates that the focus of attention had reached the far speaker by this time. Reaction time to invalid trials remained at a similar level throughout the experiment.

No head movements by the subject were observed and the subject reported no inclination to do so.

The task has therefore produced a substantial orienting effect; an valid-invalid difference in the order of 180 ms, with the effect asymptoting between 180 and 380 ms, following cue onset.

The suitability of the procedure for use in further experiments appeared confirmed.

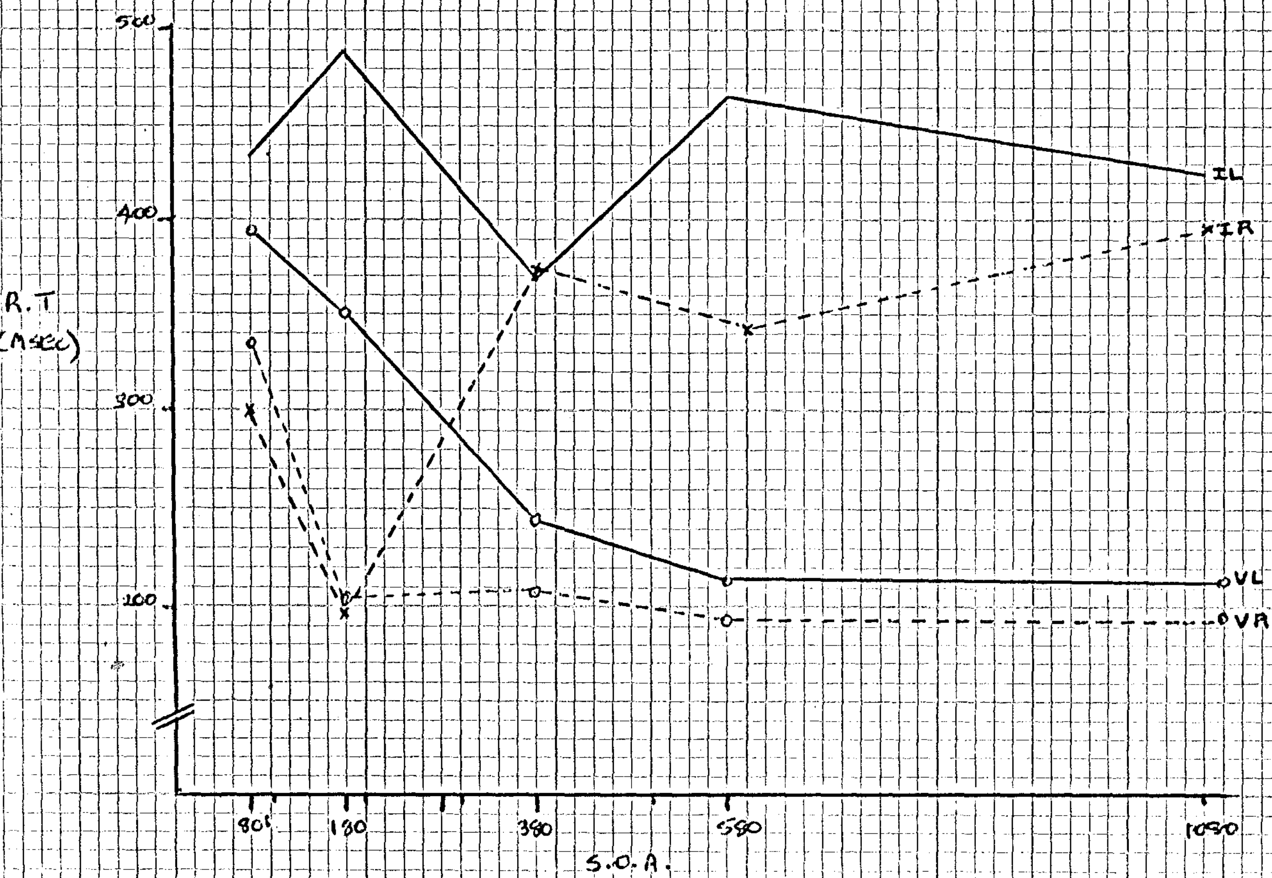

Figure 2. Experiment 2: Median RT as a function of cue validity, location and SOA.

EXPERIMENT 3

This experiment was designed to replicate, as closely as possible, the design used by Schulman et al (1979). The aim was to demonstrate analog movements of attention to auditory imperative stimuli.

Cueing subjects as to the likely location of the imperative stimulus induces them to direct their attention to that location. If attentional movements are analog, in the sense that they pass through intermediate states in their traverse (Sheperd 1975), the presence of attention should be reflected by the relative facilitation of an infrequently probed location midway between the centre and the cued locations at intermediate SOAs.

It is important, in this experiment, to arrange conditions which evoke a narrow focus of attention, for attention to be located at the centre for the beginning of each and every trial, and for its movement out to the cued location to be consistent and tightly time locked to the presentation of the cue. It was thought that the pitch cues used in Experiment 2 would achieve this tight time locking because of their short duration and the presumed attentional requirement involved in processing the information given in the cue.

Subjects were run through a preliminary block of trials in which the cue correctly predicted the location of the stimulus 100% of the time. It was thought that this would establish a strong association between pitch cue and the location of the imperative, and encourage the development of a consistent strategy to direct attention to the cued location.

Method

Subjects

Three male subjects; the thesis supervisor, the author and a friend were used.

Apparatus

The apparatus was identical to that used for Experiment 2 except that imperative tones came from one of four target locations. All four target speakers were ceiling mounted. They were placed at angles of 44.5 or 26.1 degrees to the left or right of the seated subject.

The pitch cues and the to-be-ignored tone were generated by toggling the computer tape-out address (using the same assembly language software as for the imperative tones) and were presented through an aplifier and speaker different from those used for the target locations. This centre, to-be-ignored speaker was mounted in a larger 300 x 220 x 140 box, also suspended from the ceiling.

Procedure

The procedure in essence followed that of Experiment 2. Subjects now completed the preliminary cue familiarisation block in which all trials were validly used. The SOAs; this time of 50, 100, 150, 200 or 500 ms duration were not blocked but presented at random within each 126 trial block. Within each block 26 tones were presented from the centre speaker to which no response was to be made. Of the remaining 100 trials there were four conditions of cue validity. These were; 'valid' trials, in which the imperative came from the far speaker on the side cued; 'valid-rear' trials, for which the imperative came from the new speaker on the side cued; 'invalid' trials which presented the imperative from the far speaker on the opposite side to that cued, and 'invalid-rear' trials for which the rear speaker on the non-cued side sounded.

Seventy trials per block were 'valid' with 10 trials each for the other three conditions of cue validity, making up the total of 100 trials for which RT data were recorded. All conditions of validity were equally divided with respect to side of presentation and SOA. Trials were presented in a random order, for both cue validity and SOA, within each block, with a different ordering being used for each subject and trial block. Subjects rested between each block. The whole experiment lasted approximately 90 minutes.

Results and Discussion

No orienting head moements were observed and subjects did not report any tendency to do so.

Seventy-nine anticipation errors were recorded in total, making the probability of an anticipation error on any trial 0.04. There were 42 false alarm responses recorded, (inappropriate responses to the to-be-ignored centre speaker), yielding a probability of occurrence on any trial of .10.

The possibility that subjects responded on the temporal basis of cue offset is rejected by the small number of anticipation errors. The large variance in SOA would have resulted in a very high number of anticipatory responses if this had been the case. The high-false alarm rate suggests that subjects often failed to make locational discrimination, responding instead to any presentation of the imperative tone. The high rate of false alarm responding also reflects the difficulty of the task. All subjects reported some difficulty, particularly for trials with short SOAs.

Median RTs were obtained from each subject for each combination of cue validity, SOA and side of stimulus presentation. A graph showing the median figures, averaged over all subjects and collapsed over side of presentation, is presented in Figure 3. A pattern of results showing; an emerging valid-invalid difference with increasing SOA, and a facilitation of the valid-near condition relative to the valid far condition at intermediate SOAs would provide support for the hypothesis that attention moves in an analog fashion through auditory space. No such pattern is apparent from these results although a valid-invalid difference does appear to have arisen by 200 ms. There is no reliable facilitation of the valid-near condition relative to the far condition at intermediate SOAs. Neither of the two invalid conditions show a consistent trend with SOA. If analog post imperative shifts of attention are occurring the invalid-near condition would be expected to display faster RTs than the invalid-far condition at all SOAs

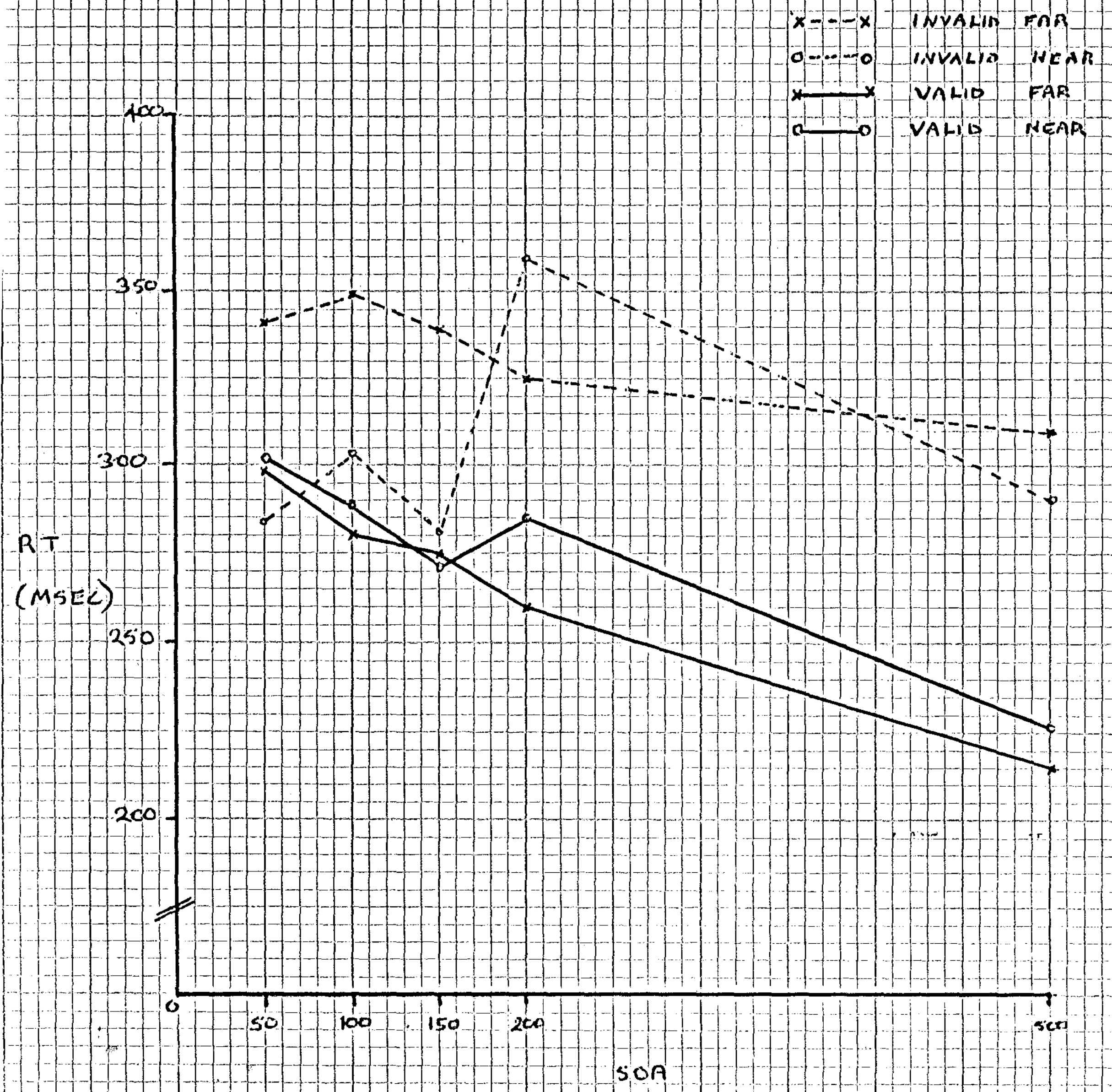

Figure 3. Experiment 3: Group mean RTs as a function of cue validity, location and SOA.

because it should always be closer to the focus of attention. Clearly this is not the case. In fact, the group average presents an overly optimistic view of the results. When plotted individually, subject results showed a very inconsistent pattern differing greatly within each condition and between subjects. It was this combination of factors which led to the decision to alter the experiment.

The five potential imperative locations, five randomly varied SOAs and the requirement to withold from responding to the centre speaker mean that subjects have to contend with overwhelming uncertainty as to the time and location of a stimulus occurrance. It was decided to alter the design of the experiment in an attempt to alleviate the difficulty subjects reported in generating expectancies and shifting attention to the expected location.

EXPERIMENT 4

In the case of vision, peripheral cues presented from a location in very close proximity to the source of the following imperative signal, are reputed to be automatic in their ability to capture attention. This automaticity results in an increased resistance to the suppression of performance by extra capacity demands, (Jonides, 1981).

It was decided to attempt to exploit this automatic capture of attention in an auditory situation. It was hypothesised that presenting a cue tone from the peripheral location which the tone suggested (from which the imperative stimulus was likely to come) would automatically draw the focus of attention to that location.

The use of peripheral cues should simplify task demands because subjects no longer have voluntarily to make the effort to direct attention to the cued location, or process the directional information contained in the pitch cues.

The to-be-ignored centre speaker was originally included to prevent subjects from relying on the automatically alerting nature of auditory stimuli and responding without directing their attention to the stimulus location. If attention is automatically captured by peripheral cues then this possibility is eliminated. The centre speaker was, therefore, excluded from the experiment which, it was hoped, would further simplify task demands and effectively increase the proportion of trials on which the cue correctly predicts the location of the imperative stimulus.

Attention would be presumed to locate itself in the centre at the beginning of every trial because of the presentation of the aural warning signal from the centre and because, when both sides are probed equally often the centre is the optimal pre-cue location.

Method

Subjects

The thesis supervisor and author served as subjects.

Apparatus and Procedure

The experiment was identical to Experiment 3 except that the cueing was now achieved by a 5,000 hz tone of 30 ms duration presented from one of the four speakers, and the to-be-ignored centre tones were replaced by a 1000 ms catch trial interval as in Experiment 1.

Results and Discussion

Rates of anticipatory and false-alarm responding were low. The probability of an anticipatory response on any trial was .02, while the probability of a false alarm response, when the subject pushed the detection key on a catch trial, was .06. These low error rates effectively rule out the possibility that subjects responded on the basis of temporal information following cue offset.

RT data were once again cutoff below 100 ms and above 1000 ms. Nine RTs (out of 1260) fell outside this range and were excluded from further analysis. Head movements were monitored by the experimenters and none observed.

Median reaction times for each condition of cue validity, side of presentation and SOA were obtained and averaged over both subjects. Figure 4 shows a graph of these results, collapsed over side of presentation. The most salient feature to emerge from the results is the clear decline in RT with SOA for all conditions, indicating a simple alerting function (Posner, 1978 Chap 5). No reliable valid-invalid difference is apparent. There is certainly no reliable facilitation of the 'near-valid' condition relative to the 'far-valid' condition of any SOA.

Two reasons may be proposed to account for this failure to produce an orienting effect. The experiment may have failed because attention was not consistently located at the centre for the commencement of each trial, or because the task did not succeed in including a finely focused beam of attention, subjects may have distributed their attentional resources across the entire range of potential stimulus locations. The first explanation is unlikely. If attention was finely focused but located equi probably at either far speaker at the beginning of every trial, the predicted pattern of results would have been produced,

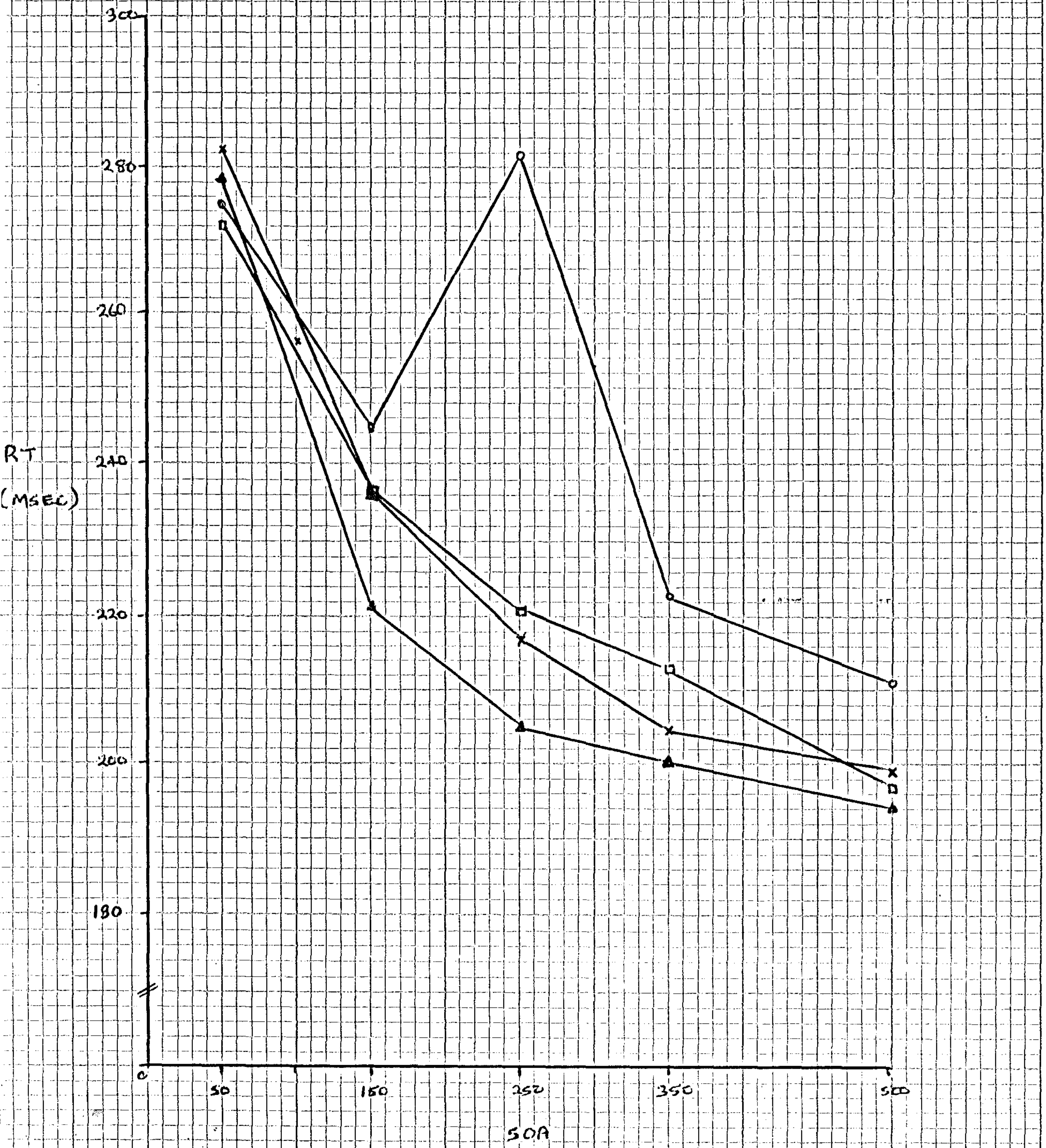

Figure 4. Experiment 4: Group mean RTs as a function of cue validity, location and SOA.

but with the effect of SOA on RT considerably lessened. Clearly this is not the case. In fact it is very hard to envisage any hypothetical pre-cue location for attention which would produce the results obtained if attention was finely focused. It seems that subjects did not adopt a finely focused beam of attention.

It is interesting to note that there is no effect of location even across the meridian between hemifields. It could be speculated that it is the central presentation of cues which, in otherwise spatially simple tasks showing no within hemifield costs and benefits (Hughes and Zimba, 1985) causes the discontinuity preventing subjects from paying attention to the entire field (Podgorny and Sheperd, 1983).

Once again subjects found the task, with its randomly varying SOAs and tone cues, overwhelming. It was decided to abandon both peripheral cueing and the entire Shulman et al design. Measures inducing objects to adopt a finely focused beam of attention appear to make the take over complicated when using auditory stimuli.

EXPERIMENT 5

An experiment designed to investigate shifts in the locus of auditory attention must achieve a constricting of the receptive field of attention sufficient to produce differential facilitation at each of the potential stimulus locations, and the consistent focusing of attention at some desired location prior to cue onset. The present experiment employs a delayed tone matching task to achieve these goals.

Subjects were required to respond only when tones occurring at two distinct time intervals were identical in pitch. Two tone pitches were used and were presented so that the tones matched on 87% of trials. It was hoped that the task of matching the tones would force a constricting of the attentional field. The first tone of the sequence was always presented from a speaker directly in front of the subject and adjacent to the voice synthesiser speaker (the 'Left' speaker). It was hypothesised that the need to retain the identity of this tone in order to match it with the second tone would locate attention at this speaker at the time Tone/sounded.

The second tone varied in location, coming from the far right speaker on 80% of trials with the remaining so % of trials equally divided between the 'Left' speaker and a "middle" speaker, located midway between the left and the far speakers. It was thought that the frequent probing of the far right position would induce subjects to shift atention from the left position to the far right on every trial. The following pattern of results would then be predicted: at brief SOAs between the two tones, matching latencies should be shortest at the left speaker and progressively longer at the other two locations. At long SOAs the reverse pattern is expected because attention will now have moved to the far right location and will have to travel inwards to permit matching. At some intermediate SOA, attention is hypothesised to be located at the middle speaker. When this occurs matching latencies should be fastest at this speaker.

Figure 5 depicts these hypothetical results graphically.

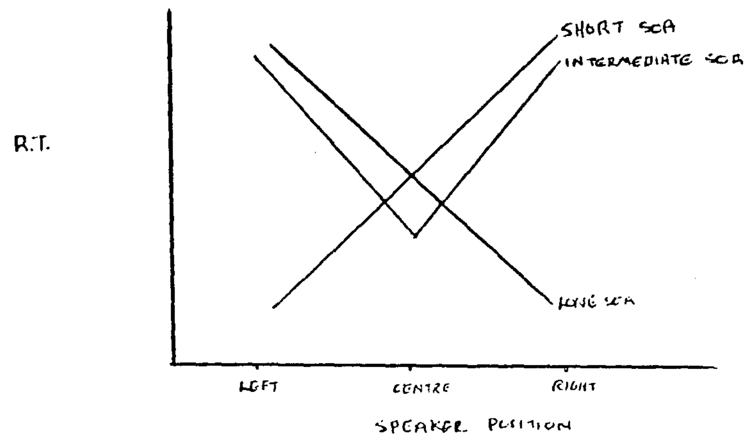

Figure 5. Experiment 5: Hypothetical results for Experiment 5; RT as a function of SOA and speaker position.

Method

Subjects

Three male subjects; the thesis supervisor, the author and a friend were used.

Apparatus

The apparatus used was the same as that common to previous experiments and used three from the set of four identical speakers and amplifiers employed in previous experiments.

The left speaker and voice synthesiser speaker were located 1.9 m directly in front of subjects, with the other two speakers 1.2 m and 2.4 m further to the right (32^{o} and 52^{o} of angle) and co-linear with the left speaker.

Stimuli and Procedure

Each trial began, as usual, with the aural warning signal "ready". This was followed by a sequence of the first tone, a variable SOA and the second tone. The tones used were of either 1300 hz or 5000 hz and were of 30 ms duration. SOAs of 100, 200, 300 and 500 ms were used.

There were 92 trials per block, 12 of which were 'different' tones divided equally with respect to the pitch of the first tone and speaker location of the second tone. The remaining 80 trials presented sequences of 'same' tones. The first tone of the sequence always came from the left speaker. The second tone was delivered from the right speaker on 80% of these trials with the other two locations each being probed on 10% of the occasions. Thse trials were also equally divided with respect to tone pitch. The conditions were presented in a random order, a different random order being used for each subject and trial block.

Four blocks of trials were run. SOA was constant within a block and they were run in the order from shortest to longest SOA for all subjects.

After responding, subjects were informed, via the voice synthesiser of their RT in milliseconds, or the type of error. The error feedback was the same as for previous experiments except that the 'no key press required' message now indicated that the key had been pressed when the two tones differed in pitch. Two seconds were allowed for feedback, followed by an inter-trial interval of between .5 and 3 seconds.

Subjects were instructed to look straight ahead at the 'left' speaker at all times. They were asked to push the response key as quickly as possible after the onset of Tone-2, if and only if Tone-1 and Tone-2 were of the same pitch. The pitches were matched for loudness across location, but the lower tones were approximately 2 louder than the higher tones at 59 and 52 dBA respectively.

Results and Discussion

Head movements were monitored and once again, none observed. Forty-two anticipation errors occurred in total, giving a probability of occurrence on any trial of .038. There were 17 inappropriate responses to different sequences of tones (false alarms), yielding a probability of occurrence of .11.

The possibility of subjects responding on the basis of the offset of the first tone is ruled out by the low number of anticipation errors. The higher rate of false alarm responding is not unexpected given that subjects are now performing a discrimination task.

Median RT for each combination of speaker location and type of tone were collected for each SOA and averaged over all subjects. A graphical representation of these results, collapsed over tone, is presented in Figure 6.

The most obvious feature of the results is the clear decline in RT with increasing SOA for all locations. An unexpected pattern, in which the far right speaker (from which 80% of the second tones were delivered) shows the shortest RT for all SOAs, is the other main feature of the results.

It appears that the presentation of the first tone did not include subjects to pay attention to the left speaker at any stage. Instead, subjects seemed to direct their attention to the likely location of the second tone, processing the first tone automatically.

Although the experiment produced unexpected results, the pattern of increasing RT with distance away from the right speaker was interpreted as reflecting the positioning of subjects' attention of this far right location, and its subsequent movement to the other locations on probe trials.

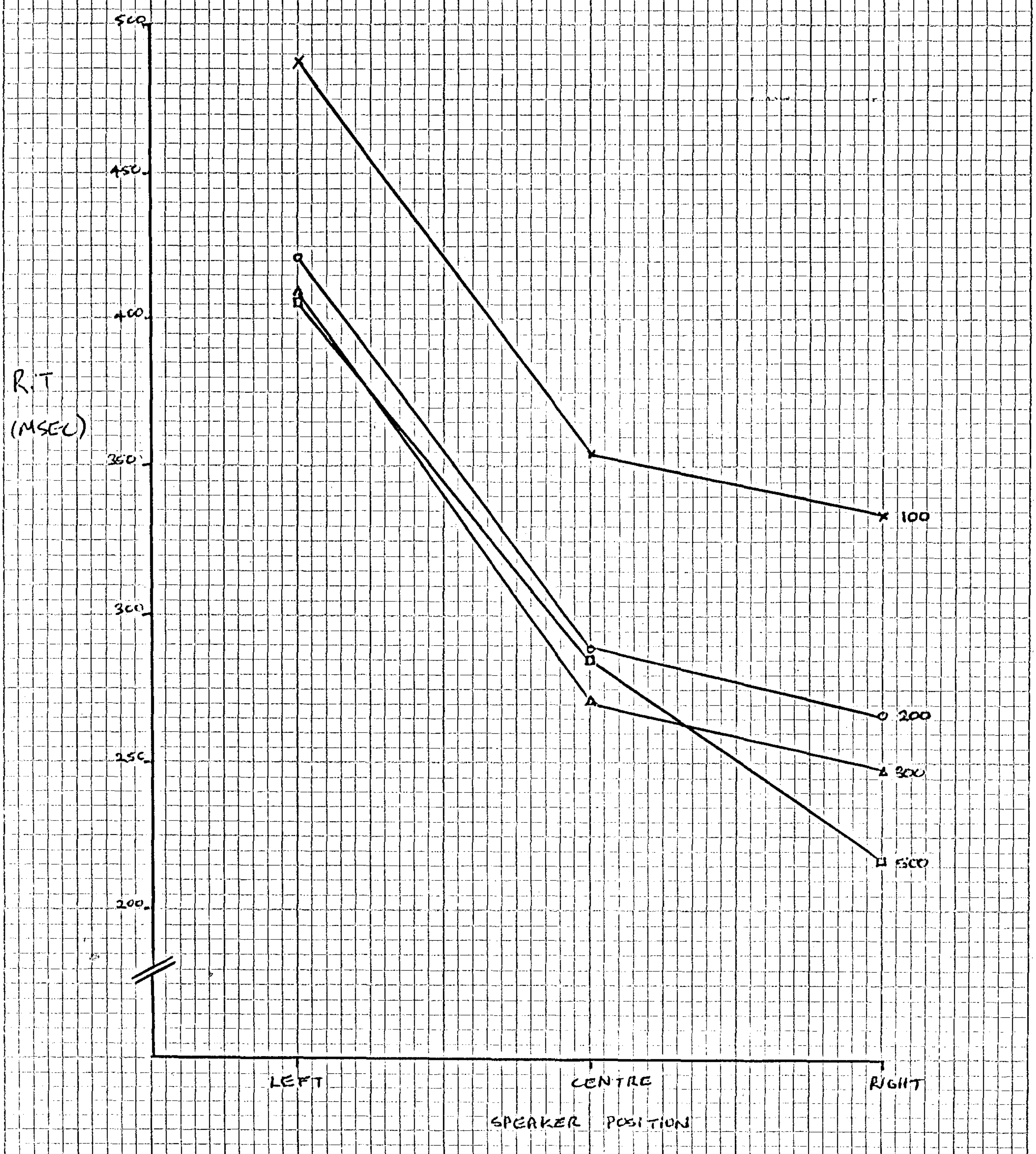

Figure 6. Experiment 5: Group mean RT as a function of speaker position and SOA.

Simply manipulating the probability that a stimulus will be presented at a given location seems capable of inducing subjects to direct their attention to that location.

Interestingly, the subject appears able to listen to Tone-1 in sufficient detail to permit a matching without having to direct attention to that location, yet to match two tones or to report their identity, attention appears necessary. These results are consistent with those of Posner and Boies (1971). Using a delayed letter match task they found that secondary task interference occurred around the time of presentation of the second letter, but not to the presentation of the first letter. It was concluded that encoding of the first letter did not require attentional resources. Similarly, encoding the first tone in the present experiment does not appear to require attentional resources either.

EXPERIMENT 6

This experiment was designed to exploit the finding that tone matching requires a narrow focus of attention, the locus of which is manipulable by the frequency with which a location is probed.

The experiment is based on Experiment 5. In this experiment however, the location of the first tone and the most probably location of the second tone are the same. Attention, it is proposed, will be focused at this location at the onset of the two in order to make a matching response. When the second tone is delivered from an infrequently probed location attention will move, following the onset of Tone 2, to this new location in order for the match to be made. Some support for the notion that attention moves in an analog fashion would be derived from results showing RT increasing as a function of the spatial separation between the focal and probed locations.

The experiment employed three colinear speakers and two groups of subjects. SOA was not manipulated. Subjects from both groups were seated directly in front of the centre speaker. For the pitch-match-right (PMR) group, the first tone and 80% of second tones were presented from the right speaker. The pitch-match-left (PML) group received first tones and 80% of the second tones from the left speaker.

It was predicted, for both groups, that RTs would increase with increasing distance of the position of the second tone from the groups focal location. A graph of RTs plotted as a function of the location of the second tone should display a cross-over pattern.

Method

Subjects

The subjects were 18 undergraduate volunteers from the University of Canterbury. Subjects were 14 male and 4 female and aged between 20 and 26 years. Nine subjects were run in each group.

Apparatus

The apparatus was identical to those used for Experiment 5 except that the speakers were now placed directly in front of the subject and 1.2 m (32^{o}) to the subjects' left and right. The voice synthesiser speaker was placed underneath the 'focal' speaker position for each group; left for the PML subjects and to the right for the PMR group. Tones were 30 ms bursts of 1300 hz and 5000 hz sound, at approximately 54 dBA. The inter-tone interval varied at random between 400 and 600 ms. Subjects now received the word 'good' from the voice synthesiser as feedback when the correctly witheld responding to a different sequence of tones. All other intervals and feedback were as for Experiment 5.

Procedure

The procedure of Experiment 5 was followed with a number of changes. Subjects completed only two blocks of 102 trials. The first block was treated as practice and allowed subjects to build an expectation as to the probable location of Tone 2. In each block there were 80 trials in which the first and second tones were of the same pitch, and 22 trials where they differed. For 80% of same-pitch trials and 82% of different-pitch trials the second tone was delivered from the focal location. Remaining trials for both same and different sequences were equally divided between the other two locations. High or low second tone pitches were equally divided between the other two locations. High or low second tone pitches were equiprobable for both same and different tone sequences and for each location. The computer generated a different random ordering of trials for each subject and each block.

Results and Discussion

Error data were compiled for both blocks of trials. Twenty-five anticipatory errors were made in total, making the probability that an anticipation would occur on any one trial .006. There were 124 false alarm responses made (responses to different sequences of tones), yielding a probability of occurrence of .15.

The probability of subjects making a false alarm error (responding to a sequence of different tones) is depicted in Figure 7 as a function of speaker location.

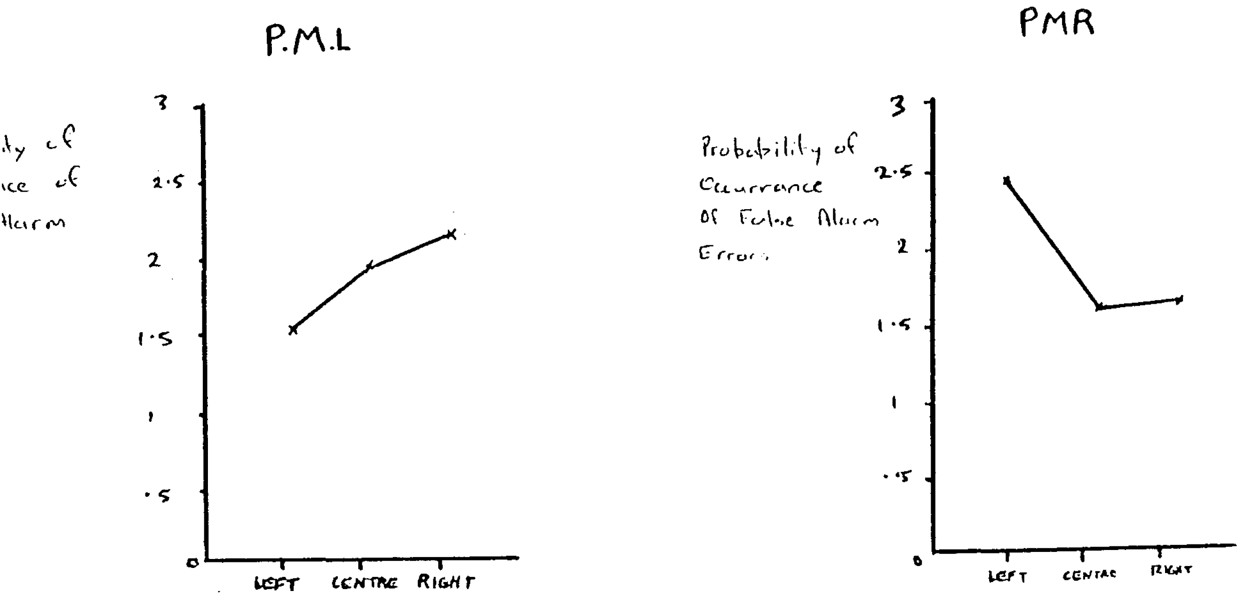

Figure 7. Experiment 6: False alarm rate as a function of speaker location.

False alarms appear to be lowest at the most frequently probed position. This result argues against any criterion setting explanation to account for the results, as such an explanation would predict higher error rates at the most frequently probed position where the criterion for responding is assumed to be lowest.

Head movements were once again monitored by the experimenter and none observed.

Seven RTs which were either less than 100 ms or greater than 1000 ms were recorded and excluded from the analysis.

The median of the remaining RTs for each subject in each pitch x speaker location condition were obtained. Group means of these medians are presented in Figure 8. For each group RT increased with the distance of the

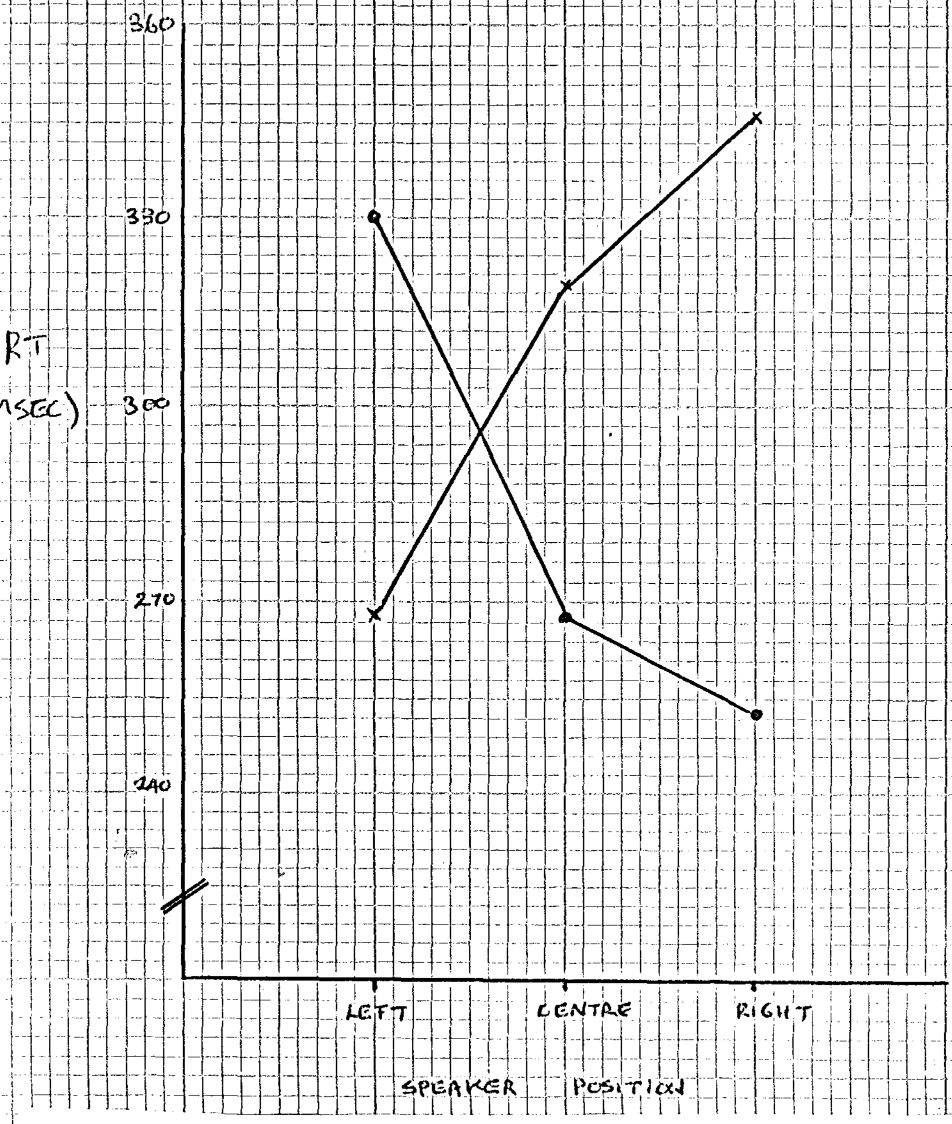

Figure 8. Experiment 6: Group mean RT as a function of speaker location, for both PML and PMR groups of subjects.

currently probed position from the focal location. Lanes (1981) general analysis of variance program was used to break the data. Adjusted degrees of freedom are cited, and have been used in the assessment of significance levels. Subject medians were treated by a groups x location x pitch analysis of variance. The groups x location interaction was significant, $\underline{F}$ (2,31) = 12.60, $\underline{P} < 0.1$. Neither the pitch main effect, nor any interaction involving pitch was significant. The PML and PMR data were then treated by separate location x pitch analyses. The location main effect was significant for both the PML, $\underline{F}$ (1,10) = 12.455, $\underline{P} < 0.1$, and PMR, $\underline{F}$ (1,12) = 14.75, $\underline{P} < 0.1$, groups. A further analysis was performed in order to compare the rate of increase in RT with distance of the probed from the focal location. Locations were redesignated in terms of "focal", "near", and "far" relative to the groups' focal location. A groups x relative location analysis was performed.

Of relevance is the groups x location effect. It did not approach significance, indicating that the rate of increase in RT with spatial separation is approximately the same for each group. Attentional shifts following the occurrence of Tone-2 appear to traverse space at the same speed regardless of the direction of the shift.

EXPERIMENT 7

A pre-condition for interpreting the results of Experiment 6 as reflecting the analog movement of attention across the auditory field, is that subjects be able to selectively direct their attention to separate, spatially distinct locations.

Subsequent to the completion of Experiment 6 a publication of experimental work by Hughes and Zimba (1985) became available.

Using simple luminance detection tasks and highly practiced subjects, Hughes and Zimba found that costs and benefits in RT, which develop as a result of the orienting of attention to selected stimuli, do not occur when all the potential stimulus locations are confined to the same visual hemifield. Hughes and Zimba proposed that the spatial extent of attention was not restricted except across the vertical meridan. They disputed that slower RTs to flashes that occur at unexpected locations are due to post flash attentional movements, and instead concluded that rather than spatial attention operating like a beam that can be positioned by an observer, an expectancy to receive a signal at one eccentric location results in modest benefits throughout that hemifield and a stronger inhibition throughout the opposite hemifield.

The present experiment was undertaken to examine the spatial extent of auditory attention. A demonstration of increasing detection latencies with increasing spatial separation from the focus of attention when all the potential stimulus locations are in the same hemifield, would establish that the results of Experiment 6 were not just an artefact of across meridian orienting.

Method

Subjects

The subjects were nine (6 male, 3 female) volunteer undergraduate students from the University of Canterbury. They were aged between 20 and 26 years.

Apparatus, Stimuli and Procedure

The design of the experiment was identical to that of the PML condition in Experiment 6 except that subjects were now seated to the left of the left-most speaker of that experiment. All the locations from which stimulus tones were presented were now in the subjects' right auditory hemifield.

Subjects were seated 1.9 m directly in front of the voice synthesiser speaker upon which they were instructed to direct their fixation. The three stimulus-tone emitting speakers remained in the same positions, relative to one another, as they were in Experiment 6. They were now located 64 cm, 158 cm and 252 cm to the right of the voice synthesiser speaker. The speakers were 19^{o}, 45^{o} and 57^{o} to the right of the seated subjects.

Results and Discussion

Treatment of raw data followed that of Experiment 6. Nine errors of anticipation were recorded giving a probability of occurrence on any trial of .004.

Fifty-four false alarm errors, made when subjects pushed the detection key to a 'different' sequence of tones were recorded, yielding a probability of occurrence of .13.

Both of these figures are similar to the error rates recorded for Experiment 6. The possibility that subjects responded on the basis of the temporal information from the offset of the first tone is eliminated by the very low rate of anticipatory responding.

The probability of subjects making a false alarm error (responding to a sequence of different tones) is depicted in Figure 9 as a function of speaker location. The far speaker location shows a significantly higher rate of false alarm responding.

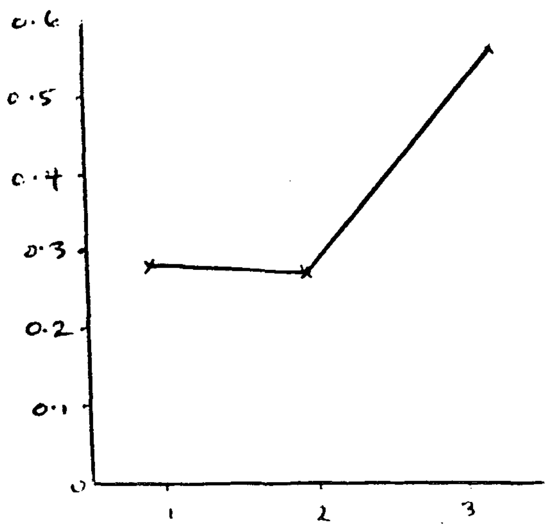

Figure 9. Experiment 7: False alarm rate as a function of speaker location.

This is precisely the trend predicted by an attentional-movement explanation. Arguments proposing differential criterion setting for the different locations are once again dismissed.

No head movements were observed throughout the experiment.

Only 3 RTs fell outside the cutoffs of 100 and 1000 ms.

Figure 10 shows median RT, averaged over all subjects and both pitches, as a function of degrees of angle away from the focal position. The results from the PML condition of Experiment 6 are included for comparison. Reaction time shows a clear increase with spatial separation from the focal position for both experiments.

The subject median from Experiment 7 were submitted to a locations x pitch, within subjects, analysis of variance. The main effect of location was significant $F(1,10) = 12.455$ $p < 0.1$.

Neither the main effect of pitch, nor the interaction between pitch and location approached significance.

Auditory attentional orienting, it appears, is not confined to situations in which the potential stimulus locations are on opposite sides of the vertical meridian. Both the pattern and the magnitude of the results for this experiment are similar to the

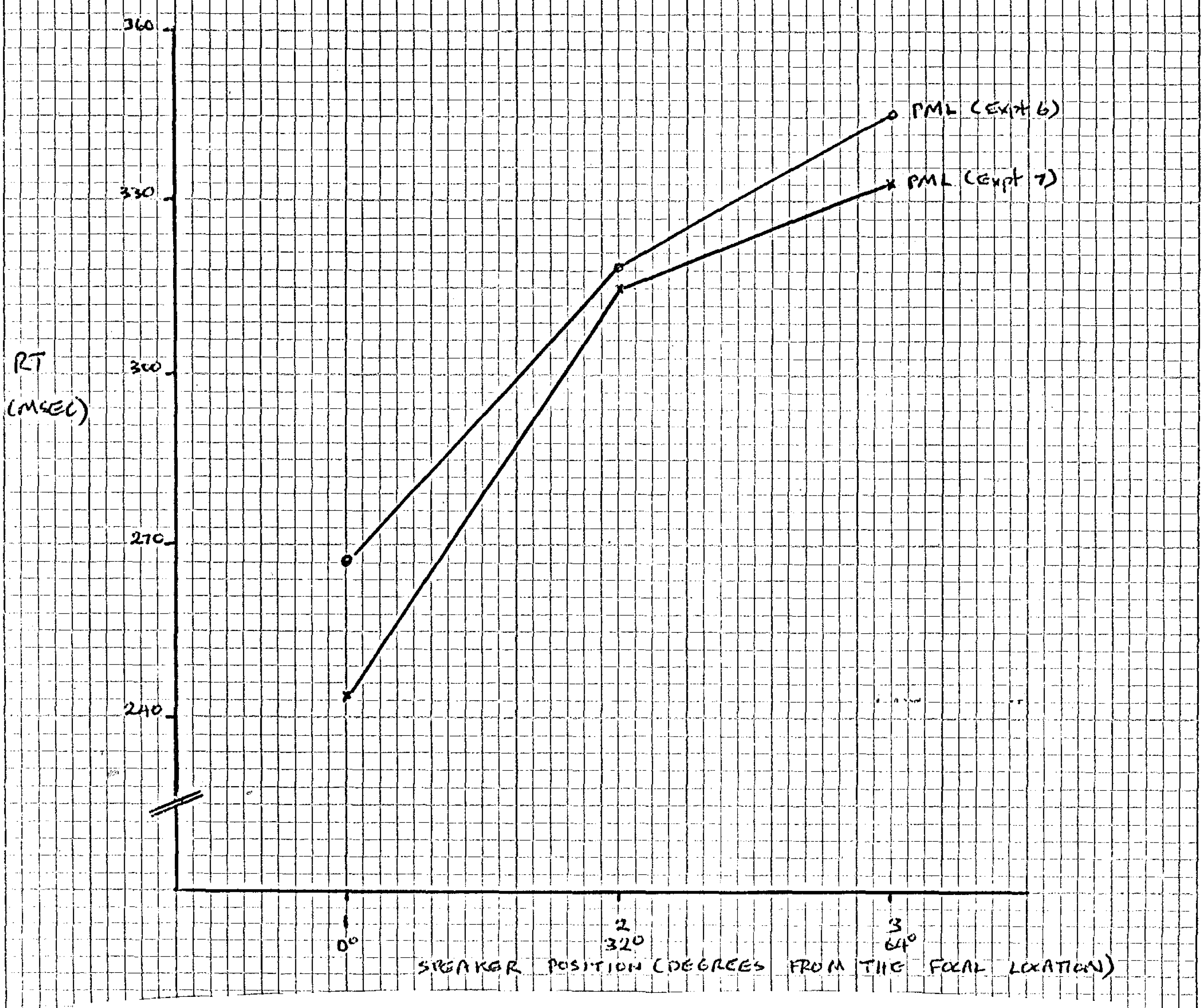

Figure 10. Experiment 7: Group mean RT as a function of spatial separation (in degrees of angle) from the focal location. (PML condition of Experiment 6 included for comparison).

results of Experiment 6. The spatial extent of attention for this pitch matching task is small enough to permit differential facilitation for each of the three stimulus locations, even when they are all in the same hemifield.

The fact that Hughes and Zimba (1985) used a simple detection task whereas the present investigation has used a matching task, prevents one from addressing the issue of whether there is a true difference between vision and audition to account for our discrepant results. It is proposed, however, that it is the differing nature of the tasks used which account for the differing results in any case. Hughes and Zimba required subjects to perform simple luminance detection in an otherwise dark field which, as already argued in the introduction, would enable and encourage subjects to maintain a large and diffuse receptive field of attention.

EXPERIMENT 8

Experiments 5, 6 and 7 have all used an identify matching task. The question inevitably arises as to whether the results showing increases in RT with distance away from the focal speaker are due, not to attentional shifts, but rather occur because the spatially disparate nature of the stimuli from the non-focal positions slows pitch matches in the same way that introducing differences in physical identity in a letter matching task does (Posner and Taylor; 1967). Cooper and Sheperd (1973) performed an experiment showing that the time taken to determine that a spatially transformed object, (for example, a visual letter rotated about its axis) is of inherently the same shape as some comparison, increases monotonically with the transformational differenece between the two objects. The spatial separation of the tones for trials on which the second tone comes from one of the unexpected locations, may act as a dimension of dissimilarity. If this were the case, a 'matching phenomena' theory would also predict the focal position to be fastest, with the speed of matching responses slowing with increasing separation of the stimuli.

This experiment requires subjects to respond only when the two tones are different. It has been shown that different judgements are faster when the two stimuli are more different (Farrell, 1986). Thus the alternative explanations for the findings of experiments 5, 6 and 7 are placed in opposition in the present experiment. When the task is to report that two spatially separated tones are of different pitch, an explanation derived from matching phenomena would predict a decrease in RT with spatial separation, whereas an attentional movement explanation makes the reverse prediction for judgements of both sameness and difference.

Method

Subjects

The subjects were nine male undergraduate students from the University of Canterbury. All were volunteers.

Design, Stimuli and Procedure

The experiment was of identical design to Experiment 7 except that the probabilities of same and different pitch pairs were reversed, and subjects were now instructed to push the detection key only when the first and second tone were of different pitch. The two tones were once again the 30 ms bursts of 1200 and 5000 nz sound at approximately 54 dBA. The left speaker was again the focal location.

Results and Discussion

Treatment of raw data followed that of Experiments 6 and 7. Head movements were monitored by experimenter observation and none were observed. Once again RTs less than 100 ms and greater than 1000 ms were rejected.

Six data were cutoff in this manner; a probability of rejection of .006.

Seventy-one false alarms were recorded (inappropriate detection by responses to a sequence of 'same' tones). This represents a probability of occurrence on each same sequence trial of .18.

The probability of a false alarm error occurring on any trial is distinctly lower at the focal speaker; .15 compared to .38 and .30 for the infrequently probed locations. Any suggestion that the results may reflect the adoption by subjects, of a lower criterion for responding at the focal position, is rejected.

Figure 11 shows median RT, averaged over subjects and pitch of the first tone, as a function of speaker location. Reaction time appears to be independent of speaker location. The medians were treated by a within subjects, location x pitch analysis of variance. Once again using Lane's (1981) general analysis of variance program. None of the effects approached significance.

The results, showing no effect of speaker location on RT are not consistent with either of the explanations proposed to account for the results of Experiments 6 and 7. It may be that judgements of difference, especially between such disparate pitches, do not result in a

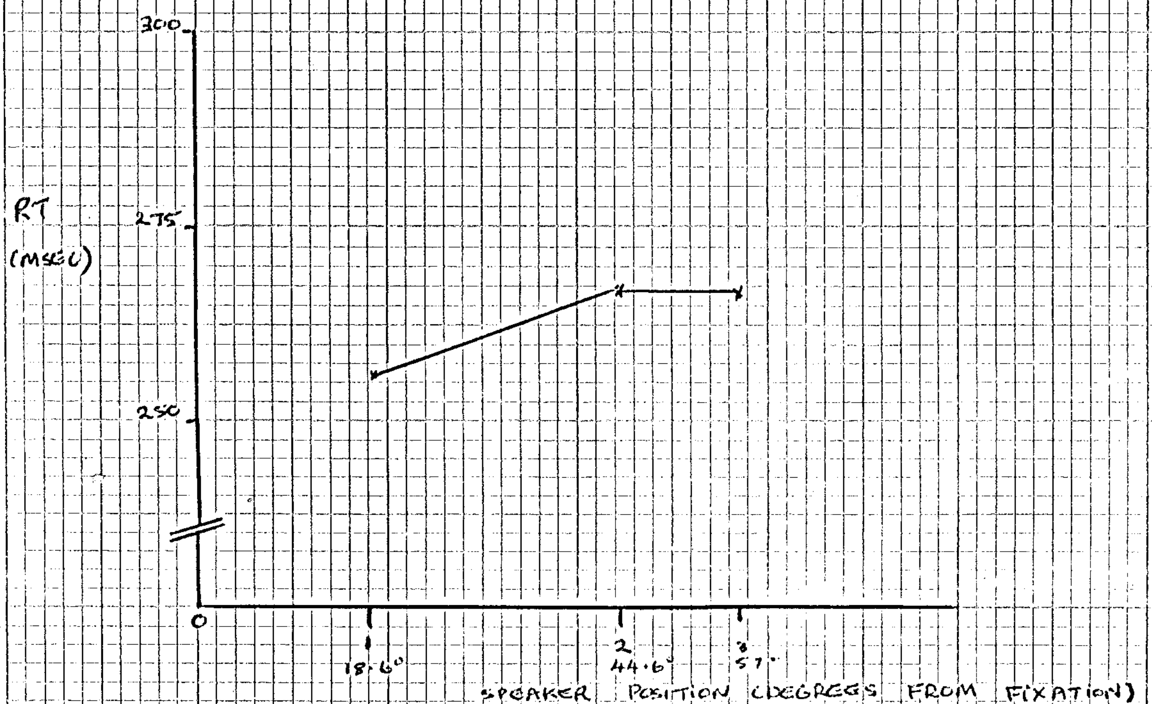

Figure 11. Experiment 8: Group mean RT as a function of speaker position.

small enough constriction of the receptive field of attention to produce differential facilitation for each location. This seems unlikely however, given the lower rate of false alarm responding for the focal position. An experiment using tones of more similar pitch might produce an orienting effect and thereby resolve the issue.

An alternative explanation of these results is that both tone matching and attentional movements are implicated in producing the results of Experiments 6 and 7. The independence of RT from speaker location in this experiment is due to these two effects cancelling one another when placed in opposition. Without further experimentation, no firm conclusions can be drawn.

DISCUSSION

The present study provides forceful evidence for the assertion that spatial separation is a dimension which is able to affect the speed of human information processing. This effect appears to be analog in the sense that increments of spatial separation result in corresponding movements in reaction time in a continuous manner. The issue of whether this occurs as a result of attentional movements, or because spatial separation is a dimension affecting matching tasks in a manner analagous to, for example, Sheperd's (1975) manipulation of letter rotation is not entirely resolved. These two explanations are not necessarily incompatible as attentional priming has been a feature of some of the recent models proposed to explain matching phenomena (Farrell, 1986). The contentious state of the theoretical explanations of matching phenomena, however, preclude one from taking any firm stance on this issue.

Unfortunately, efforts to induce orienting by forcing subjects to make discriminations have led us away from the simple model task paradigm advocated by Posner (1978), and our ability to account for the results is compromised as a consequence. An experiment which may resolve the issue is proposed which employs a simple tone detection task in a format otherwise similar to Experiment 6. Attention would be drawn to the focal location by probability and move to the other locations for probe trials as in Experiment 6. The task however would be simple detection rather than matching, with extraneous background noise, for example music or randomised tone bursts, forcing a discrimination on the locational dimension. A repetition of the pattern of results achieved in Experiments 6 and 7 under these conditions would represent a persuasive argument in favour of an attentional movement explanation.

Regardless of the explanation(s) one adopts, the analog effect of spatial separation on RT would appear to require a degree of within hemifield discrimination inconsistent with the conclusions of Hughes and Zimba (1985), proposing that one cannot selectively direct one's attention toward a particular stimulus location in preference to other locations in the same hemifield. Hughes and Zimba were careful to largely confine their conclusions to their simple luminance detection paradigm, however even within this paradigm attention has been shown to selectively enhance the processing of spatially distinct stimuli occurring in the same hemifield; (Shulman et al, 1979; Downing and Pinker, 1986).

A reconciliation of these results is provided by both Jonides (1983) two stage model of orienting phenomena, which suggests two alternative modes of attentional distribution; either distributed over a large extent of the visual field or capable of operating in a focused mode, and its recent successor. Eriksen and Yei-yu-heh's (1986) analogy of attention as a Zoom lens capable of a continuous range of resolving power, "from an even distribution over the entire field to highly focalised concentration subtending as little as a fraction of a degree of angle."

La Berge (1983) has achieved convincing experimental results in favour of a variable spatial extent for visual attention by imposing different conditions of a discrimination requirement on his subjects. Evidence was provided for a 'spotlight width' of attention which corresponded to the size of the stimulus subjects were required to categorise, (either single letters, five letter words or five letter non-words).

Hughes and Zimba's task would appear to be toward the simplest end on a continuum of task requirements, a feature that would encourage subjects to keep their attention diffuse rather than concentrated. When a discrimination is required, as in our tone matching task or Eriksen's experiment (in which subjects had to respond only to two target letters), it seems that within hemifield orienting is a distinct reality. Results from tone matching task (Experiment 6), showing increased matching latencies for locations away from the most frequently probed location of the experiment, were in no way diminished when all the potential stimulus locations were in the same hemifield (Experiment 7); if anything they were increased.

The role of the vertical meridian in inducing costs and benefits may be due to the nature of the neural circuitry of the visual system as Hughes and Zimba proposed, or possibly because the presentation of the cue from the centre creates a discontinuity between the two hemifields over which attention cannot extend. Posner, Nissen and Ogden (1978) and Podgorny and Sheperd (1983) have previously suggested that subjects cannot concentrate attentional capacity into disjoint areas of the visual field simultaneously.

The apparent ability of subjects, in a number of the experiments reported, to orient their attention to auditory imperative stimuli is support for Russell's (1985) assertion that the ability to selectively enhance the processing of stimuli on the basis of location is not limited by the modality to which those stimuli are presented. This view is fully in accord with Posner's (1978) general theory of orienting phenomena, which regards orienting as the alignment of attention with the psychological pathway upon which the subject expects the imperative stimulus to be presented. It seems unlikely that subjects who can orient to stimuli on the basis of their semantic attributes, (Neely, 1977), would be unable to direct their attention to the pathways involved with the localisation of sounds in space.

Results demonstrating advantages in processing due to early selection when subjects are pre-cued as to the likely colour; (Francolini and Egeth, 1980; Russell,

1985) or Pitch, (Dunford, 1984) of the imperative, suggest that orienting is unaffected by the dimension upon which the imperative stimuli differ. It seems that as long as one can generate an expectancy for the presentation of a certain stimulus, then one can make beneficial preparations which will aid with its subsequent processing.

Posner's (1978) failure to induce orienting to auditory imperatives may have been due to the requirements of the task which his subjects had to perform. Orienting is an undoubtedly effortful process, if subjects can report detection of the imperatives without having to direct their attention to their location, it appears that they will do just that. This is especially likely in cost-benefit tasks, in which orienting may be contrary to the task instructions (to minimise RT) because of the costs incurred on invalid trials.

An interesting issue arising from the experiments reported concerns the relative roles of cueing and the actual probability of a stimulus occurring from a given location, in controlling subjects' orienting behaviour. The most successful experimental designs for inducing orienting, Experiments 5, 6 and 7 did not present subjects with any locational cues at all. Attention was directed to a location simply because subjects knew that the probability of that locations being probed was vastly greater than for the other locations. To do so was therefore a sound strategy to adopt. This is contrary to an assertion by Posner (1980) that subjects had to be cued on every trial to successfully induce orienting. It is tempting to speculate that the reason for this was that the centrally presented cue created a discontinuity across which attention could not spread and thereby induced an orienting effect in this simple detection task, otherwise devoid of any discrimination requirement.

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